

**UPGRADING OF INDUSTRIAL
STEAM TURBINE SST-900 TO
MEET NEW CUSTOMER
REQUIREMENTS IN UTILITY
AND INDUSTRIAL
APPLICATIONS**

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Answers for energy.

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Abstract:

The traditional world of power generation in the range of 150 to 250 MW is changing. We can recognize the following trends:

- industrial customers are going for bigger units above 150MW
- both utility and IPP (Independent Power Plant) customers are asking for improved cost performance ratio in this power output range
- pressure to reduce emissions combined with the desire for reduction of fuel consumption is driving efficiency improvement

The focus of this paper is to present how the above-mentioned trends influence the design of the steam turbine. Siemens has decided to upgrade the SST-900 from its industrial steam turbine portfolio and to implement design solutions from utility turbine design in the existing SST-900 turbines. The proven last-stage blade family from the Siemens utility turbines is one example that has been introduced into the upgraded SST-900.

Additionally, the output level is significantly increased. Initially limited to 150 MW, now the SST-900 output is increased to the 250 MW range in reheat applications, with strong potential for further development. Inlet steam conditions are up to 585° C and 165 bar (a) with potential for controlled extraction up to 50 bar.

This upgraded and highly flexible turbine has already proven successful in combined-cycle power-plant (CCPP) applications, not only together with Siemens gas turbines but also with gas turbines of other brands. A number of machines have also been sold to the metals industry for captive power plants and coal-fired power plants. Examples will be referenced in Korea, Thailand, India and Oman.

Introduction

The Oil and Gas Division of the Energy Sector is responsible within Siemens AG for steam turbines for utility and industrial applications in the power range up to 200+ MW. Siemens as market leader in this business is obliged towards its customers to be attentive to market trends, listen to its customers to meet their current needs and requirements and develop solutions for applications and needs to come.

Market trends were the stimulus for the development and upgrade of the new SST-900 steam turbine family:

- Industrial customers from traditional industries such as pulp & paper, chemical and steel, are building up bigger captive power plants to provide electricity and steam for their

ever-larger industrial plants. Selling surplus electricity to the grid is profitable business, given the current market situation. Seeing a growing demand for new industrial steam turbines above 150 MW, including the capability to handle process steam, we developed a solution providing increased steam flow and power capabilities

- Governments are pushing strongly to generate electricity and steam in an environmentally friendly manner. This means meeting more and more stringent emissions limits and reducing emissions of CO₂. One of the most economically viable solutions to reduce emissions is to increase the efficiency of electricity production. Improving thermal efficiency of the steam water cycle can be achieved in a variety of ways:

- By reheat applications. The reheat concept is based on live steam run through a high-pressure (HP) turbine. Before entering the low pressure (LP) turbine, the steam is returned to the steam generator to increase its temperature to the live steam parameters (pressure remains as is). This solution improves the net power plant efficiency by 1-2%.
- By designing the turbine with higher operating conditions. Live steam parameters are increased up to 140 bar (a) 560°C for non-reheat applications and up to 165 bar(a) 585°C for reheat applications, with reheat temperature up to 580°C. Increase of net power plant efficiency by increasing inlet steam temperature can yield an additional 1-1.5% higher efficiency.
- By installing a steam turbine with high internal efficiency and low losses. To this end we are concentrating continuous development efforts on improving blade geometries and reducing leakage losses.

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History of the SST-900 steam turbine

The SST-900 (earlier also known as ATP4 and ST5) Intermediate Pressure (IP) Turbine (Fig. 1) was developed during the mid-nineties, as a complement to the already existing and well-established VAX-turbines. The first unit was delivered and put into operation during 1998.

The VAX-turbine family (today named SST-700, earlier also known as ST6) was structured as a dual-casing concept, with two high-speed turbines. Both High Pressure (HP) and Low Pressure (LP) turbine modules have individual and optimized speeds, and are connected via speed-reduction gears to the dual-end-drive generator. The VAX-turbine family was developed and introduced on the market in the early 1980's, focusing on the power range 5-

75MW. The reason for the SST-900 development was to increase the power range that could be served and consequently the new IP-turbine was focused on the 50-130MW range in non-reheat applications. A major target application was the combined cycle, but as the turbine was an integral part of the industrial range, options for controlled extractions (constant steam pressure) and bleeds (sliding steam pressure) were also included in the product structure. With respect to the power range served, the IP-turbine was optimized for direct connection to 50 and 60Hz generators.

When the increasing demand for mid-range reheat applications appeared in the late 1990's, an attractive solution was formulated, by combining the geared HP-module (Fig. 2) from the SST-700 family with the SST-900 IP-turbine. With this concept, the power range up to 150MW could be served, with an efficient and compact solution.

Basic design features

During the development of the SST-900 IP-turbine, a number of requirements were addressed, in order to fulfill the demands from the industrial market at that time:

- Low life-time cost
- Compact installation
- Low weight
- Short delivery time
- Flexible to customer needs

First development target was non-reheat applications, as shown in Fig. 3. The compactness and low weight was achieved by utilizing impulse blade technology (integrally shrouded) with high heat-drop for each stage. This gives in addition high thermoflexibility, enabling short start-up times and rapid load changes, due to the disk-rotor concept used. Combined with the LP exhaust blades of reaction type, and using retractable seals with abradable surface, enabling small clearances, this solution gives a performance level representative for the focused power segment. Additionally, the turbine casing was designed with the smallest possible diameters, minimizing material weight and cost, creating just sufficient space for the blade path, including diaphragms and diaphragm carriers, inside the casing. Process-steam extraction and bleed boxes were placed on the outside of the casing, by welding on fabricated plates to form the necessary chambers, symmetrically placed on the upper and lower half.

Furthermore, the support of the casing was defined by flexible plates (legs) in the front end and by utilizing the axially placed condenser to support the rear end of the turbine. By this arrangement, not only compactness and easy access for service was achieved, but also a reliable heat expansion concept without sliding parts could be utilized, simply by bending deformation of the flexible legs. Easily accessible boroscope openings are provided to allow inspection with a minimum of disassembly needed, as well as openings provided for rotor field-balancing.

The requirements of flexibility and short delivery time can be seen as somewhat contradictory. To achieve both targets, a building-block structure of predefined and pre-designed parts was decided upon, parts that can be arbitrarily combined to define a customized steam turbine (Fig. 4). This means that a number of inlet sections were defined to cover the variation of live-steam conditions as well as sliding pressure or part-load efficiency requirements, for the individual installations. Additionally a number of mid-sections with different lengths were defined to cover the requirement for different numbers of stages and resulting rotor length. In these mid-sections, options to add extraction and/or bleed, as well as additional steam-admission functionality, were included. Furthermore a number of exhaust-end sections of different sizes, covers the variation in steam volume flow, coming from the variation in mass flow and condenser pressure levels. This includes a number of LP blades and guide vanes of fixed design as well as casing sections covering the blade path internals. Finally, exhaust casings for axial or radial steam flow, one size for each size of LP-blade section, is selected, depending on whether the condenser is placed axially for a low foundation or under the foundation table.

For reheat applications, where the IP-turbine is utilized to expand the steam coming from the reheat boiler, the expansion of live steam down to cold reheat steam takes place in the geared high-speed HP-turbine as shown in Fig. 5. In this power range, with the high live-steam pressures and comparable low volume flows, the design of the HP part is critical. Using a synchronous-speed 50 or 60 Hz HP will result in a non-optimal blade path, with high shaft-diameters and short blades, thus introducing losses. Therefore the concept of high-speed HP-turbine was decided, giving a short rotor with a lower number of stages, and a low shaft-diameter, thus a more compact overall design. The blade length will then be increased, giving a higher efficiency. Additionally, the casing is of barrel design, without a thick split-plane flange, and can therefore allow shorter start-up time and quicker load change, still keeping the thermal stresses at a moderate level.

To ensure full utilization of this design structure, a number of computational design tools are included in the design-calculation software package. This includes software for thermodynamic calculation and performance optimization, mechanical integrity-check of blades, rotor disks, guide vanes and diaphragms, and selection of predefined valve designs. It also includes software for verification of lateral and torsional rotor vibrations, and additionally software to define customized casing, rotor, blade and guide vane design drawings, for immediate start of the sourcing process for the long-lead items.

Not only the core turbine, but also a number of turbine-related auxiliary systems have been predefined and pre-designed to support the same requirements. This includes lubrication and control-oil systems, gland and leakage steam systems as well as instrumentation and turbine operating and control system (Siemens Simatic S7[®]).

To reduce installation time on site, turbines, generator, auxiliary systems and optional speed-reducing gears, are all fully workshop-assembled upon delivery.

Design Upgrades

The latest upgrades of the SST-900 IP-turbine have been focused mainly on improving efficiency and increasing power output capability. With the continuous market-driven demand for improved cost-performance ratio, these are natural steps in order to support the 150-250MW power-generation market. An additional driver is the increasing demand for process steam in this power range, which traditionally is not so well supported by current utility-sized steam turbines. Four different upgrades will be described here, without mentioning all the smaller incremental improvements of the different components based on feedback from fleet operation.

3D blade geometry

To improve efficiency and minimize incident losses, a 3D blade design (Fig. 6) has been introduced at the rear end of the turbine, in the last stages upstream of the fixed-design LP stages. When the blades become longer and longer, the difference in ratio between flow velocity and blade rotating-speed at hub and tip diameter respectively, becomes larger and larger. Thus, the velocity vectors over the blade length change dramatically and it is no longer possible to find an optimized blade with a straight profile. With a twisted 3D-profile over the length of the blade, the incident angles can be kept constant, thus avoiding the corresponding incident losses. Additional effects are achieved in the shroud sealing, where the twisted blade profile gives a stronger support for the integral shroud plate, and an

additional number of seal strips can be used to decrease the leakage losses still further. This blade design was introduced a few years ago.

Increased steam temperature

Another way to increase efficiency is to enable higher live steam and/or reheat steam temperature. The original design of the SST-900 IP turbine had a limit of 540°C on live-steam temperature in non-reheat applications, and 565°C on reheat steam temperature. The limit was defined with respect to rotor-material temperature limitation due to scaling of material and mechanical integrity limitation of the inlet section, including First-stage blade. This was a strong restriction as in many applications, the more optimal operating conditions are up to at least 560°C in non-reheat and up to 580°C in reheat applications. This restriction has now been eliminated by two measures and the required temperatures can be managed. The latest material development and operational experience with Siemens Utility Steam Turbines has qualified and confirmed the use of the rotor material (22CrMoNiWV8 8) for higher temperatures. Also the design of the inlet section and the first-stage blade were improved to overcome the mechanical-integrity limitation. Therefore live-steam temperature up to 560°C is now enabled in non-reheat applications, with a stand-alone IP-turbine. The first units where this is applied are currently under production in Siemens workshops, ready for delivery during 2009.

For reheat applications, as previously mentioned, the SST-700 HP-turbine is used to expand the steam down to the reheat boiler. The SST-900 IP-turbine operates downstream of the reheater and there a feature was introduced in order to permit reheat-steam temperature up to 580°C. By using the cold reheat-steam from the HP-turbine exhaust, and feeding it into the chamber outside the IP-turbine inlet-gland area, a cooling-steam supply could be utilized. The pressure drop over the reheater is sufficient to drive an appropriate and optimized cooling flow through the IP inlet gland and further to the first-stage rotor disk and blade. The first unit with this kind of cooling device has been in successful operation for many years.

Larger LP-sections

Finally, the LP-exhaust size is often the limitation in many cases. If the exhaust section is too small for the steam flow requested, the steam velocity is increased with corresponding exhaust losses. Therefore the implementation of the high-performance LP blades, used for several years in Siemens Utility Steam Turbines, substantially increased the flow capacity. These well proven steel LP-blades for 50 and 60 Hz applications, see table 1, fit very well

into the design structure of the SST-900 IP-turbine. With this upgrade, an exhaust area up to 12.5 m² for 50Hz and 8.7m² for 60 Hz applications can be applied, which is an order of magnitude larger than for traditional industrial steam turbines. This is a cornerstone to fulfill the needs in the 150-250MW market, which have been served up to now by small utility steam turbines. An additional benefit is also achieved by the increased efficiency of the shrouded LP blades compared to traditional free-standing blades (Fig.7). Typically 1-2% higher efficiency can be achieved on the LP-section itself, by the improved steam flow in the blade top section and decreased leakage over the blade tip. The first units with this upgrade are currently in production in Siemens workshops ready for delivery in early 2009. The LP blade design itself has a long history of experience of, for some sizes, more than 20 years of implementation in the Siemens utility steam turbines.

Welded shaft

With the combination of increased steam temperature and increased LP blade sizes, the IP-shaft will be exposed to two distinctly different environments on each end. The IP-end must endure high temperature-creep while the LP-end must have high yield-strength to support the large last-row rotating blades. The IP-LP rotors for such operating requirements have typically used a single rotor forging with different heat treatment applied to each end. However, this rotor with dual heat-treatment is expensive and procurement time from a limited number of forging suppliers is often long.

To address the shortcomings, the IP-LP rotor was changed to welded design (Fig. 8), so that two different rotor materials (22CrMoNiWV8 8 and 27NiCrMoV15 6), which both are ideally suited for their respective operating conditions, could be used. The use of two smaller forgings increases availability of material and shortens lead time. The welding procedure, used for many years within Siemens Utility Steam Turbines, is known to produce material properties at least equivalent to those of the base materials used.

References

During the last couple of years a number of references have been delivered, utilizing some of the design upgrades described. These upgrades have increased the efficiency and improved the flexibility of the SST-900 turbine model in various applications. The possibility to use single-flow exhaust all the way up to very large exhaust areas has a double advantage since axial exhaust can be utilized with improved efficiency and costly double-flow exhausts can be avoided. One of the first examples of these upgraded SST-900's in Southern and Eastern

Asia was turbines in a captive power plant for Jindal steel works in Karnataka, India. These turbines were followed by a number of turbines for other steel works in Orissa and Gujarat, India. Today over 900 MW have been installed or are near commissioning in various steel plants, fueled by coke-oven gas, coal and natural gas.

Orders have also been received in South Korea for a large steel-plant installation for Hyundai Green with 4x115 MW reheat. Another example in South Korea is a 115MW power plant currently under erection which is to burn coal and fragmented tires. Steam turbines for combined-cycle power plants(2x163 MW reheat) have also been sold to Oman, through Korean EPC contractors, for a water desalination power plant and to customers directly in Indonesia (130 MW non-reheat). Recently, orders have also been received by a ferronickel company active in New Caledonia (2x135 MW reheat) as well as an alumina refinery in Western Australia (2x56 MW reheat back-pressure process turbines).

Conclusion

The SST-900 IP-turbine was introduced on the market during the second half of the last decade and since then has served the industrial market for reheat and non-reheat applications, up to 150MW. With the latest development steps, the capability is now enhanced up to 250MW and more. This has been achieved partly by continuous development steps and partly by implementation of features used in the larger-sized Siemens Utility Steam Turbines. The benefit brought to the market is a steam turbine with improved cost-to-performance ratio and design flexibility including process-steam capabilities.

Figures and Tables

Speed (rpm)/ Frequency (Hz)	Exhaust area (m ²)	Blade length (inches)
3000 / 50	6.3	31.4
	8.0	36.3
	10.0	38.5
	12.5	45.1
3600 / 60	6.9	32
	8.7	37.6

Table 1: LP last stage blade family

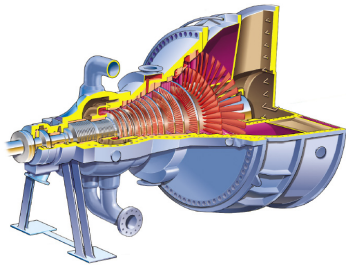


Fig. 1: SST-900 Intermediate Pressure (IP) Turbine

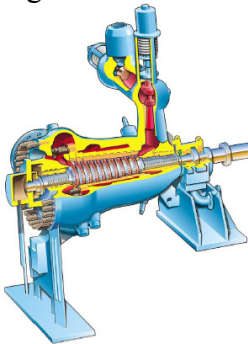


Fig. 2: High-speed High Pressure (HP) Turbine used in reheat applications

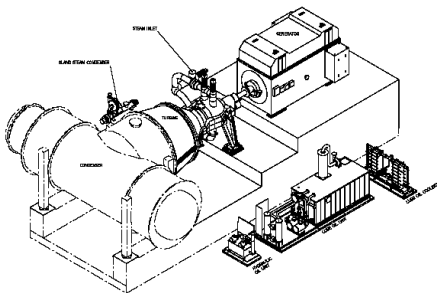


Fig. 3: SST-900 for non-reheat applications

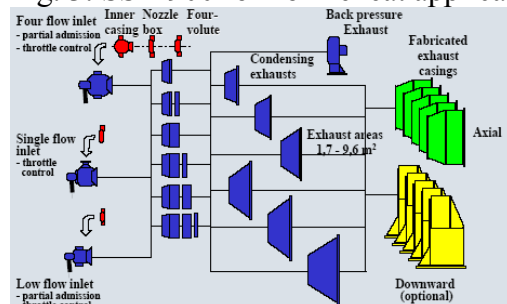


Fig. 4: Turbine building-block structure of predesigned parts

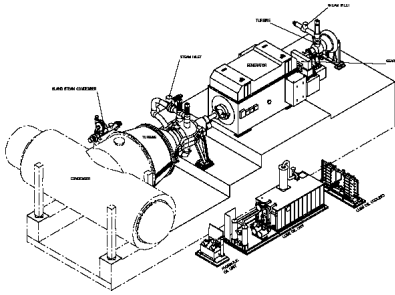


Fig. 5: SST-900 for reheat applications

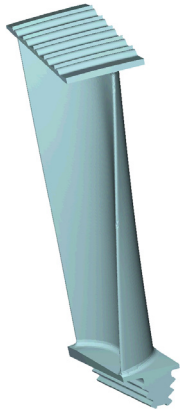


Fig. 6: 3-D blade design



Fig. 7: Fixed-design LP blade

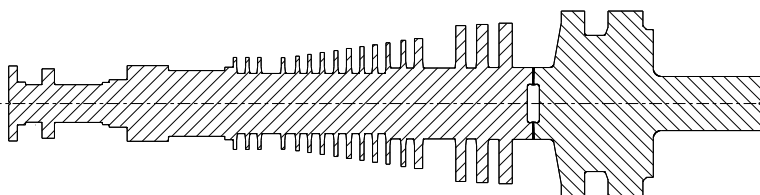


Fig. 8: Welded IP rotor

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